UTE-based Short-T2* Mapping and PLM Optical Imaging for Evaluating Disruption of Collagen Fibers in the Knee Cartilage Explants

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INTRODUCTION

A trauma to the knee joint that tears ACL and/or meniscus often concurrently damages articular cartilage and its collagen network[1, 2]. Disruption of well-organized collagen fibers tends to build up local high pressure that further damages collagen fibers and exposes chondrocytes to injury disabling natural healing pathways and triggering subsequent progressive loss of damaged cartilage that leads to post-traumatic osteoarthritis (PTOA)[3, 4]. Noninvasive assessment of the disruption would allow identification of cartilage damages requiring protective interventions. Currently, there is no noninvasive approach that can fully assess collagen fiber disruption due to lack of investigative methodologies. To break down this barrier, a novel idea was proposed to utilize the specific short T_2 relaxation from the internal water molecules trapped within collagen fibrils as a potential endogenous imaging biomarker for quantifying the disruption[5, 6]. Here presented are preliminary results from the studies on cadaveric cartilage explants to demonstrate the feasibility of that idea in comparison with the optical images produced by the polarized light microscopy (PLM) which is very sensitive to the arrangement of collagen fibers and thus is a good reference modality.

METHODS AND EXPERIMENTS

Methods The short-component T_2* relaxation time and intensity were calculated by fitting the measured T_2* decay curve into a model of bi-exponential decay at a pixel in cartilage regions on a set of T_2*-weighted MRI images acquired at different TEs. The PLM optical images were registered onto the T_2* maps to compare the findings from both modalities. ***Experiments*** Five tibial plateau explants harvested from intact cadaveric knee specimens (age 18-82 years) were studied on a clinical 3T MRI scanner (Magnetom Trio Tim, Siemens Medical Solutions, Erlangen, Germany) with an 8-channel knee coil (Invivo, Gainesville, FL, USA), under an approved IRB protocol. The explants were positioned with its cartilage/tibia interface parallel to the main field $\boldsymbol{B}_0$. A UTE sequence AWSOS[7] was used for the T_2*-weighted imaging with FOV=100mm, matrix size=256, in-plane resolution=0.39mm, slices = 40 at 2mm thickness, flip angle=30°, TR=100ms, 11 TEs between 0.5-40ms, in-plane spirals=64, spiral readout =5.28ms, and TA=4.3 min for one TE image. The optical imaging of cartilage sections (picrosirius red stained, 6μm thick) was performed on a Nikon TE2000-U polarized light microscopy (Nikon, Chiyoda-ku, Tokyo, Japan) at an angle of 45° for the cartilage surface against the two polarizers to highlight both superficial and deep zones of the cartilage[8]. The registration between the MRI and PLM images was secured via a special registration plate[8]. ***Multi-component T2* mapping*** The bi-exponential fitting was based on a multi-component model and NNLS-based automatic iterative algorithm[6].

RESULTS AND DISCUSSION

Figure 1 demonstrates PLM images at three locations on an MRI slice, showing collagen fiber disruption at mild to severe grades (Fig. 1b2-b3), compared with the normal arrangement (Fig. 1b1). In Figure 2 are the UTE MRI image and T_2* maps of the cartilage explant shown in Fig. 1. A cut-off between the short- and long-T_2* time was 11ms. A normal region at core 10 (Figs. 1a, b1) has an average short-T_2* time of 5.6ms in the bottom half and an average long-T_2* of 13.9ms in the top half (Figs. 2c-f). A severely abnormal region in the bottom half at core 6 (Fig. 1a, b2) may suggest a loss of collagen fibers (and bulk water) but has no collagen fiber disruption, and has an average short-T_2* time of 6.3ms (Figs. 2c-f). Another abnormal region in the bottom half at core 2 (Fig. 1a, b3) shows a mild loosening of collagen fibers (and may suggest a loss of trapped water) and has an average long-T_2* time of 11.3ms (Figs. 2c-f). However, so far we do not know whether these findings are common in cartilage and how they relate to loss of cartilage. Our next step will be studying more explants to consolidate these correlations and see how they are related to cartilage functioning and PTOA development.

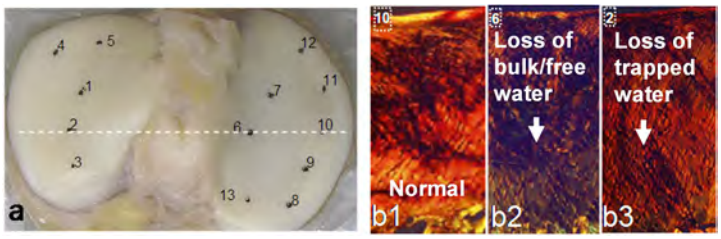

Fig. 1. (a) Cadaveric cartilage explant with the locations of PLM cores (black dots) and MRI slice (dashed line), and (b) PLM images of the cartilage at cores 2, 6, and 10, showing collagen fiber disruption (b2-b3).

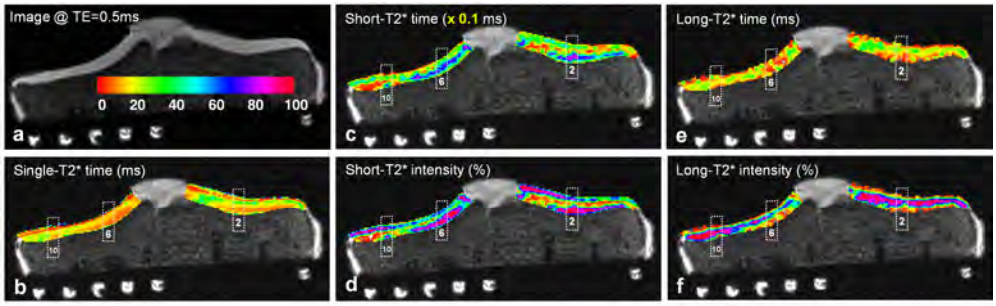

Fig. 2. (a) UTE image of the cartilage explant in Fig.1a, (b) single-component T2* map, and (c-f) two-component T2* maps, showing the short-T2* in (c, d) is sensitive to disorganization of collagen fibers.

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